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Traffic-related trace elements in soils along six highway segments on the Tibetan Plateau: Influence factors and spatial variation

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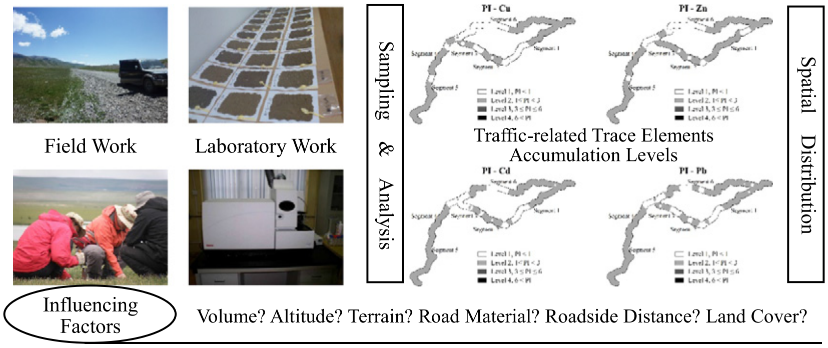
HIGHLIGHTS

- In this study area, Cu, Zn, Cd and Pb in roadside soils were identified to be mostly related to traffic.
- Cd and Pb showed greater levels of accumulation than Cu and Zn.
- The maximum distance of influence ranged from 16 m to 144 m perpendicular from the road edge.
- Of six highway segments studied, the highway from Putonquan to Lhasa with higher traffic volume, greater proportion of high-emission vehicles, and higher altitude showed greater levels of accumulation.

GRAPHICAL ABSTRACT



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ABSTRACT

The accumulation of traffic-related trace elements in soil as the result of anthropogenic activities raises serious concerns about environmental pollution and public health. Traffic is the main source of trace elements in roadside soil on the Tibetan Plateau, an area otherwise devoid of industrial emissions. Indeed, the rapid development of tourism and transportation in this region means it is becoming increasingly important to identify the accumulation levels, influence distance, spatial distribution, and other relevant factors influencing trace elements. In this study, 229 soil samples along six segments of the major transportation routes on the Tibetan Plateau (highways G214, S308, and G109), were collected for analysis of eight trace elements (Cr, Co, Ni, As, Cu, Zn, Cd, and Pb). The results of statistical analyses showed that of the eight trace elements in soils, Cu, Zn, Cd, and Pb were primarily derived from traffic. The relationship between the trace element accumulation levels and the distance from the roadside followed an exponential decline, with the exception of Segment 3, the only unpaved gravel road studied. In addition, the distance of influence from the roadside varied by trace element and segment, ranging from 16 m to 144 m. Background values for each segment were different because of soil heterogeneity, while a number of other potential influencing factors (including traffic volume, road surface material, roadside distance, land cover, terrain, and altitude) all had significant effects on trace-element concentrations. Overall, however,

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concentrations along most of the road segments investigated were at, or below, levels defined as low on the Nemero Synthesis index.

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1. Introduction

From a soil biogeochemical cycling perspective, road traffic in addition to industry has been confirmed as a primary source of trace elements (Harrison et al., 1981; Smolders and Degryse, 2002; Wiseman et al., 2013). This has been a great cause for concern for >40 years as traffic increases all over the world (Zhang et al., 2015). In China, according to data from the Statistical Yearbooks of Qinghai (Statistics, 2014a) and Tibet (Statistics, 2014b), following economic reform in 1979, the lengths of highways in operation, passenger-person-kilometers, and the volume of freight transport have been increasing steadily in China. Especially since 2000, the values of these indexes have increased rapidly to at least three times their levels before 1979. On the Tibetan Plateau, however, because there is very little industry, this part of China presents an ideal research opportunity to explore how and to what degree traffic has affected the accumulation of trace elements. Sampling sites can easily be selected far from farmland, residences (Yan et al., 2013a), and other anthropogenic influences.

Elements known to be associated with traffic include Cu, Zn, Pb, Cd, Cr, Co, Ni, As, Ba, Sb, Mn, V, Pt, Pb, and Rh (Hjortenkrans et al., 2006; Lough et al., 2005; Sternbeck et al., 2002; Wiseman et al., 2013; Zhong et al., 2012), most occur in trace amounts. Concentrations of these elements are mainly the result of three traffic-related processes (Chen et al., 2010; Harrison et al., 1981; Suzuki et al., 2009): (1) deposition resulting from the combustion of fossil fuels, (2) wear and tear of vehicle components (either against each other or with the road), and (3) loss of the road surface due to friction. Specifically, the majority of Cu originates from tearing of tires (Winther and Slentø, 2010); As is mainly derived from the abrasion of brake linings; Ni results from brake wear, engine oil leakage, tire wear, and road abrasion; Co comes from tires; Cr originates from brake linings, engine oils, fuel, and road abrasion (Winther and Slentø, 2010); while Zn also comes from the abrasion of brake linings, tearing of tires, and engine oils (Adachi and Tainosho, 2004; Winther and Slentø, 2010). Cd is mostly derived from engine oils, abrasion of brake linings, and tearing of tires (Winther and Slentø, 2010).

Pb is commonly known to originate in leaded gasoline with 200 mg/kg of Pb, even though today the gasoline used is Pb-free, some volume of Pb is still present (17 mg/kg) (Legret and Pagotto, 1999). In China leaded gasoline was phased out step by step around 2000 (Zhu et al., 2014), especially in developing or less-developed areas, the step was much slower. Taking into account Pb accumulation from the leaded gasoline era (Kelepertzis et al., 2016), the main source for this metal remains fuel consumption (Jaradat and Momani, 1999). Pb can also be derived from tires, brakes, lead wheel weights and the yellow paint on roads (Adachi and Tainosho, 2004, Winther and Slentø, 2010). Furthermore, gasoline also contains some amount of other trace elements, e.g., As, Cd, Cr, Cu, Ni and Zn (Winther and Slentø, 2010).

Particles containing trace elements diffuse in air and are deposited, or transferred into roadside soils by dust deposition, precipitation, and runoff (Werkenthin et al., 2014). Thus, their relative amounts and distribution are affected by traffic volume (Ozkan et al., 2005), length of highway operation time (Bai et al., 2009), friction between the tire and the road (Zhang et al., 2012a), altitude (i.e., oxygen concentration) (Zhang et al., 2012a), wind (Liu et al., 2015), vegetation coverage (Yan et al., 2013b), and terrain (Saeedi et al., 2009). As a result, the accumulation concentration in roadside soil varies by location (Xiong, 2013).

Studies based on samples from different road segments on the Tibetan Plateau showed that not every potential trace element had a significant accumulation (Zhang et al., 2015). The rank of potential ecological risk contribution to the local environments among the eight traffic-related trace elements was Cd > As > Ni > Pb > Cu > Co > Zn > Cr (Yan et al., 2013a). The concentrations of Cd and Pb in roadside soils increased with traffic volume (Yan et al., 2013b), while the concentrations of Cu, Zn, Cd, Pb in the soils decreased as the roadside distance increased (Wang et al., 2014). However, none of these studies covered the length of the Qinghai-Tibet highway, the major highway in the Tibetan Plateau, while few comprehensively investigated the potential influence factors using multiple statistical analyses methods.

By focusing on broader road segments with varying traffic volume, road surface material, vegetation cover of roadside soil, terrain, and altitude etc., the aim of the present research was to identify traffic-related trace elements, analyze influence factors, evaluate levels of accumulation, and determine the large-scale spatial distribution of potential ecological risks, so as to provide guidelines for highway design and transportation management in the Tibetan Plateau that contribute to alleviating the potential environmental impact of traffic activities. The special influence factors identified in this study area will help understand the release and accumulation processes of traffic-related trace elements in other high mountain areas.

2. Materials and methods

2.1. Study area

The Tibetan Plateau region mainly consists of mountains with widely distributes with quartz, feldspar, calcite, mica, and some hornblende, smectite, and scapolite, etc. (Sun et al., 2007; Team, 1990). These bedrocks comprise the unique compositions of major and trace elements in the soils on the Tibetan Plateau. For example, compared with the upper continental crust, the concentrations of As, Cs, B, Bi, Li, Cr, Ni are much higher (Li et al., 2009; Sun et al., 2007).

Besides the parent materials source, trace elements in soils can be also related to long-range transportation, anthropogenic contribution, and so on (Botsou et al., 2016; Luo et al., 2015). Previous studies in Tibet showed that the major and trace elements (including the eight trace elements of this study) in wet deposition were mostly affected by local soil rather than long-range sources (Cong et al., 2007; Cong et al., 2010; Li et al., 2009; Luo et al., 2015). It should be noted that the study area is influenced by two main atmospheric currents – the Indian Monsoon with prevailing southerly winds in summer, and westerly circulation in other seasons (Cong et al., 2010).

A total of 49 sampling sections were selected along National Highways G109 and G214, and Provincial Highway S308 on the Tibetan Plateau, as shown in Fig. 1 (coordinates: 29°30′ N–36°53′ N, 90°30′ E–101°45′ E; altitude: 2755–5000 m). A maximum sampling distance (100 m) was defined, considering the mountainous area and the surface condition of the roadside soil. The road base height ranged from 0.1 m to 4 m, while the road base width was between 0.1 m to 10 m. All soil samples were taken at and beyond the edge of road base materials, which were gravel and sand. Samples were collected where there was no human habitation within eyesight, in order to make sure that traffic was the principal anthropogenic influence of the roadside environment. Separated by nodes, six segments of the highways were selected for comparison with each other. Highway profiles, including the locations and characteristics of the six sampling segments, are shown in Table 1. G109 in particular is a vital communication link onto the Tibetan Plateau,

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